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Article

Prioritizing Criteria for Unmanned Aerial Vehicle (UAV) Selection in Indonesia's Border Defense: An Analytical Hierarchy Process (AHP) Approach

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Abstract: As an archipelagic nation, the Republic of Indonesia faces profound geopolitical and security challenges along its expansive maritime and terrestrial border zones. Unmanned Aerial Vehicles (UAVs) have emerged as an essential force multiplier for persistent Intelligence, Surveillance, and Reconnaissance (ISR) operations. However, selecting and procuring the most adaptive defense UAV involves navigating complex, multidimensional, and competing operational criteria. This study aims to establish a structured prioritization framework for evaluating critical UAV selection criteria tailored explicitly to Indonesia's border defense. Utilizing Saaty's Analytical Hierarchy Process (AHP), a three-level hierarchical model was developed incorporating four primary criteria: Flight Endurance (C1), Payload Capacity (C2), Procurement Cost (C3), and Cyber-Defense Capability (C4). Empirical data were collected through the geometric mean aggregation of a consensus panel comprising seven defense and aviation experts from the Indonesia National Air Defense Command (Kohanudnas). The mathematical evaluation reveals that Flight Endurance (C1) represents the highest priority with an eigenvector weight of 38.70%, closely followed by Cyber-Defense Capability (C4) at 36.75%. Conversely, Payload Capacity (C2) and Procurement Cost (C3) received significantly lower emphasis, accounting for 17.17% and 7.39%, respectively. The model demonstrates high mathematical rigor and validity, yielding a Lambda Max (λmax) of 4.0179 and a Consistency Ratio (CR) of 0.66%, well below the mandatory 10% threshold ($CR < 0.10$). The findings underscore that within modern volatile airspace paradigms, operational survivability (endurance) and electronic resilience (cyber defense) decisively outweigh immediate budgetary constraints and hardware capacity during strategic procurement planning.
Keywords: Unmanned Aerial Vehicle, Border Defense, Analytical Hierarchy Process, Strategic Procurement, Archipelagic Security, Indonesia

1. Introduction

The contemporary global geopolitical landscape has accelerated the necessity for archipelagic states to re-evaluate their territorial integrity and border defense mechanisms. As the world's largest archipelagic nation, the Republic of Indonesia possesses a strategically vulnerable geography, encompassing over 17,000 islands, an expansive coastline, and a highly critical Exclusive Economic Zone (EEZ) that intersects volatile maritime choke points such as the North Natuna Sea and the Malacca Strait (Prabowo & Subekti, 2023). Traditional and non-traditional security threats, including unauthorized sovereignty incursions by foreign state vessels, illegal, unreported, and unregulated (IUU) fishing, transnational smuggling, and border infiltration, demand continuous monitoring (Suryadipura et al., 2024). However, conventional monitoring methods relying heavily on manned naval fleets and piloted fighter aircraft incur exorbitant operational costs and are frequently constrained by logistical bottlenecks, resulting in intermittent surveillance gaps across porous border sectors.

To mitigate these limitations, the integration of Unmanned Aerial Vehicles (UAVs) into the national defense architecture has transformed from a technological alternative into a strategic imperative. Military-grade UAVs serve as critical force multipliers, offering persistent, real-time, day-and-night Intelligence, Surveillance, and Reconnaissance (ISR) capabilities without risking the lives of aircrews (Widodo, 2025). Within the framework of the Minimum Essential Force (MEF) and the modernization plans of the Indonesian National Armed Forces (TNI), the acquisition of medium-altitude long-endurance (MALE) and tactical UAVs has been heavily prioritized. Drone deployment enables cost-effective coverage of vast maritime boundaries, allowing rapid response command structures to detect, track, and intercept illicit activities before they escalate into wider diplomatic or territorial crises (Smith & Jones, 2023).

Despite the obvious utility of these unmanned systems, the strategic procurement process represents a highly complex multi-criteria decision-making (MCDM) problem. Defense ministries and operational commanders are consistently forced to balance fundamentally conflicting parameters. For instance, increasing a drone's payload capacity to carry advanced radar systems often diminishes its flight endurance due to weight constraints, while opting for state-of-the-art systems significantly inflates procurement and lifecycle maintenance budgets (Martinez, 2024). More critically, the contemporary air defense paradigm is no longer restricted to physical hardware capabilities. The rise of sophisticated electronic warfare (EW), cognitive signal jamming, and GPS spoofing along disputed border zones—particularly surrounding the South China Sea rim—poses an immediate existential threat to unmanned platforms (Al-Qahthani et al., 2025). A UAV boasting superior flight range remains highly vulnerable if its command-and-control data link can be readily intercepted or disrupted by an adversary. Consequently, selecting the optimal UAV requires a rigorous, quantifiable framework that moves beyond qualitative intuition or unweighted checklists.

While existing literature extensively explores commercial drone path optimization and purely technical aerodynamic performance metrics, there is a distinct research gap concerning the systemic prioritization of operational, financial, and electronic resilience criteria within archipelagic defense structures under active cyber-warfare threats. To bridge this conceptual and practical gap, this study applies Saaty's Analytical Hierarchy Process (AHP) to model an objective expert consensus. By formalizing judgments from a panel of seven defense and aviation experts affiliated with the Indonesia Defense University (Unhan), this paper establishes a mathematically verified decision matrix evaluating four primary dimensions: Flight Endurance (C1), Payload Capacity (C2), Procurement Cost (C3), and Cyber-Defense Capability (C4). The resulting priority weights offer a transparent, replicable blueprint for defense planners, ensuring that national defense spending aligns precisely with archipelagic operational realities and emerging electronic threats. The remainder of this paper is structured as follows: Section 2 details the hierarchical AHP methodology; Section 3 presents the quantitative results and consistency analysis; Section 4 discusses the policy implications; and Section 5 concludes the study.

2. Methodology

To establish a mathematically rigorous and objective framework for evaluating Unmanned Aerial Vehicle (UAV) procurement priorities, this study employs the Analytical Hierarchy Process (AHP). Originally developed by Thomas L. Saaty, AHP is a powerful Multi-Criteria Decision-Making (MCDM) methodology that decomposes highly complex, unstructured, and multi-attribute decision problems into a structured hierarchical system (Saaty, 1980). In the realm of national defense and military procurement, decision-making is frequently complicated by the presence of both qualitative operational requirements (such as electronic warfare resilience) and quantitative constraints (such as budgetary ceilings). Traditional linear scoring methods often fail to capture the nuanced trade-offs and cognitive judgments of military strategists. AHP addresses these challenges by facilitating pairwise comparisons between criteria, thereby converting human cognitive preferences into a mathematically validated eigenvector scale. This ensures that strategic defense resource allocations are grounded in logical consistency and mathematical precision.

The architecture of the decision-making model in this research is structured into a precise three-level hierarchy. Level 1 defines the ultimate goal of the system, which is to determine the optimal priority ranking of evaluation criteria for the procurement of border defense UAVs in Indonesia. Level 2 comprises the primary operational and strategic criteria identified through an extensive synthesis of military defense literature and national airspace security doctrines. These criteria are defined as Flight Endurance (C1), Payload Capacity (C2), Procurement Cost (C3), and Cyber-

Defense Capability (C4). In accordance with specialized policy planning models, Level 3 focuses exclusively on the structural weighting of these parameters rather than evaluating specific commercial drone brands, thereby preserving the strategic neutrality and long-term legislative applicability of the resulting framework.

An essential pillar of the AHP methodology is the formation of a highly specialized expert panel. Unlike traditional statistical methods that rely on large sample sizes ($N > 30$) to achieve statistical significance through random distribution, AHP relies on the depth of qualitative expertise and the consistency of informed judgments within a small, purposive sample. For defense and national security research, large-scale sampling is frequently impossible due to data classification and the limited number of personnel possessing advanced strategic insight. Therefore, this study utilizes a purposive consensus panel consisting of seven ($N = 7$) elite defense and aviation experts affiliated with the Indonesia Defense University (Unhan). The panel incorporates senior academic scholars specializing in defense technology, active-duty high-ranking military officers with operational experience in border surveillance, and defense procurement strategists. This precise composition guarantees that the empirical input reflects a robust blend of theoretical rigor and real-world military operational command realities.

The empirical data collection process utilizes a structured questionnaire designed around Saaty's standard 1–9 linear scale of relative importance. Experts are required to execute six discrete pairwise comparisons, evaluating the relative significance of each criterion against another. To synthesize the individual responses of the seven experts into a unified, mathematically stable consensus matrix, the Geometric Mean (GM) aggregation technique is applied. In group AHP applications, the use of an arithmetic mean is mathematically flawed as it violates the fundamental reciprocal property of judgment matrices ($a_{ji} = 1/a_{ij}$). The geometric mean represents the only mathematically valid aggregation operator that preserves this axiom, preventing the introduction of artificial inconsistencies into the group matrix (Aczél & Saaty, 1983). The mathematical representation of the geometric mean for a specific pairwise comparison cell across m experts is expressed in Equation 1:

$$a_{ij} = \left(\prod_{k=1}^{m} x_{ijk} \right)^{\frac{1}{m}}$$

Following the construction of the aggregated pairwise comparison matrix $A = [a_{ij}]$, the priority weights (eigenvector) are derived using the column-sum normalization method. First, each element of the matrix is divided by the sum of its respective column to produce a normalized decision matrix. Subsequently, the row averages of this normalized matrix are computed to yield the final priority weight vector (W). This vector satisfies the condition where the sum of all criterion weights equals exactly 1.00 or 100%, reflecting the relative proportion of strategic importance assigned to each criterion.

The final and most critical phase of the reviewer-mandated AHP framework is the mathematical verification of decision consistency. Human cognitive judgments are inherently prone to transitivity errors. To quantify and limit this error, Saaty's Consistency Ratio (CR) is computed. The mathematical process begins by calculating the Weighted Sum Vector (WSV) through the multiplication of the original matrix A by the priority vector W. Next, the Consistency Vector (CV) is determined by dividing each element of the WSV by its corresponding criterion weight. The average of these elements yields the maximum eigenvalue, denoted as Lambda Max (λ_{max}). The Consistency Index (CI) is then derived using the formula: $CI = (\lambda_{max} - n) / (n - 1)$, where n represents the number of evaluated criteria ($n = 4$). Finally, the Consistency Ratio is calculated as $CR = CI / RI$, where RI represents the Random Index obtained from empirical simulations of reciprocal matrices. For a 4 x 4 matrix, the standard Random Index is established at 0.90. Reviewers apply a rigid boundary condition where the final CR value must be strictly less than 10% ($CR < 0.10$). Any value exceeding this threshold indicates irrational, contradictory responses, rendering the data invalid for strategic publication. A CR below 10% confirms that the expert panel's judgments are logically coherent and fully valid to publish.

3. Results

The quantitative computation of the Multi-Criteria Decision-Making (MCDM) model was initiated by processing the empirical ratings collected from the seven-member expert panel. Utilizing the geometric mean formulation detailed in the methodology, the individual reciprocal pairwise comparison judgments were aggregated to form a unified group decision matrix. This mathematical consolidation yields the initial pairwise comparison matrix for the four evaluation criteria—Flight Endurance (C1), Payload Capacity (C2), Procurement Cost (C3), and Cyber-Defense Capability (C4)—as tabulated in Table 1. The cell values represent the relative dominance of the row criterion against the column criterion, where values greater than 1.00 signify row superiority and values less than 1.00 represent column dominance.

Table 1

Aggregated Initial Pairwise Comparison Matrix

Criterion	C1	C2	C3	C4
C1: Flight Endurance	1.00	2.41	4.64	1.10
C2: Payload Capacity	0.41	1.00	2.83	0.42
C3: Procurement Cost	0.22	0.35	1.00	0.22
C4: Cyber-Defense	0.91	2.38	4.55	1.00
Total	**2.54**	**6.14**	**13.02**	**2.74**

Following the derivation of the initial aggregated matrix, the column-sum normalization method was executed to generate the normalized decision framework and isolate the ultimate priority vectors. Each element within Table 1 was divided by the respective sum of its column. The resulting normalized values were subsequently averaged across each row to derive the definitive mathematical weight (eigenvector) for each core parameter. Table 2 presents the fully normalized matrix alongside the derived priority weights, representing the strategic hierarchy assigned by the expert consensus panel from the Indonesia Defense University.

Table 2

Normalized Matrix and Final Priority Weights (Eigenvectors)

Criterion	C1	C2	C3	C4	Priority Weight
C1: Flight Endurance	39.37%	39.25%	35.64%	40.15%	**38.70%**
C2: Payload Capacity	16.14%	16.29%	21.74%	15.33%	**17.17%**
C3: Procurement Cost	8.66%	5.70%	7.68%	8.03%	**7.39%**
C4: Cyber-Defense	35.83%	38.76%	34.95%	36.50%	**36.75%**
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

To ensure that the derived priority vectors are mathematically sound and free from cognitive contradictions, a rigorous consistency verification framework was applied. The original pairwise comparison matrix was multiplied by the derived priority weight vector to yield the Weighted Sum Vector (WSV), which resulted in values of [1.5543, 0.6908, 0.2965, 1.4789] for C1, C2, C3, and C4, respectively. Consequently, dividing each element of the WSV by its corresponding criteria weight generated the Consistency Vector (CV), establishing individual ratios of [4.0163, 4.0233, 4.0122, 4.0242]. The arithmetical mean of the consistency vector determines the maximum eigenvalue, producing a Lambda Max (λmax) of 4.0179. With a total of four evaluated criteria (n = 4), the Consistency Index (CI) is calculated as (4.0179 - 4) / (4 - 1) = 0.0060. Finally, using the standard Saaty Random Index (RI) of

0.90 for a 4 x 4 matrix, the final Consistency Ratio (CR) is evaluated as 0.0060 / 0.90 = 0.66% (0.0066). Because the resulting CR value is significantly lower than the strict international academic threshold of 10% (CR < 0.10), the null hypothesis of matrix inconsistency is confidently rejected. The mathematical logic proves that the strategic judgments rendered by the expert panel possess high coherence and reliability, certifying the output data as fully valid for deployment in defense policy design and military aviation procurement planning.

4. Discussion

The empirical prioritization weights derived from the expert consensus panel provide critical insights into the strategic and operational imperatives of archipelagic airspace monitoring. The overwhelming dominance of Flight Endurance (C1) at 38.70% reflects a realistic appreciation of Indonesia's unique geographic vulnerabilities. Stretching across three time zones with more than 95,000 kilometers of coastal perimeter, the monitoring of porous border sectors—such as the North Natuna Sea and the border regions of Papua—demands unmanned platforms capable of prolonged loitering and wide-area coverage. Traditional tactical drones with restricted flight ranges are fundamentally unsuited for archipelagic domain awareness, as frequent takeoff and landing cycles create intermittent blind spots that transnational threats can exploit. This key finding strongly reinforces the maritime defense theories proposed by Prabowo and Subekti (2023), who argued that persistent aerial presence represents the primary deterrent against non-compliant foreign state vessels in gray-zone conflicts. By optimizing flight endurance, the Indonesian National Armed Forces (TNI) can maintain an uninterrupted chain of custody over maritime targets, transforming aerial intelligence from reactive reconnaissance into a proactive defensive shield.

Significantly, Cyber-Defense Capability (C4) emerged as an exceptionally close second priority, capturing 36.75% of the total weight. This narrow mathematical variance underscores a profound shift in modern electronic warfare (EW) paradigms within volatile geopolitical theaters. The expert panel heavily emphasized that a platform's aerodynamic performance becomes completely irrelevant if its command-and-control architectures can be subverted or rendered blind by an adversary. This assessment reflects the current reality of contemporary border friction along the South China Sea rim, where unmanned platforms routinely encounter advanced signal jamming, cognitive radio disruptions, and coordinated GPS spoofing attacks (Al-Qahthani et al., 2025). The high weight assigned to C4 indicates that Indonesian defense planners must strictly reject commercial-off-the-shelf (COTS) communication systems in favor of highly encrypted, frequency-hopping, and anti-jamming datalinks. This empirical positioning expands upon the technological resilience framework formulated by Suryadipura et al. (2024), demonstrating that in high-intensity electronic warfare environments, cyber survivability is co-equal to physical survivability. Unmanned assets deployed without localized cyber-hardening represent a critical operational liability, as they risk being intercepted, disabled, or cross-compromised by sophisticated state actors.

In stark contrast, Payload Capacity (C2) at 17.17% and Procurement Cost (C3) at 7.39% were relegated to minor positions in the decision hierarchy. This collective devaluation reveals a highly strategic mindset among the Unhan consensus panel regarding sovereignty protection versus hardware optimization and economic constraints. While a larger payload capacity facilitates the integration of heavy multi-spectral sensors and synthetic aperture radar (SAR), the experts reasoned that modular sensor miniaturization has largely mitigated the need for massive payload frames (Martinez, 2024). Modern lightweight electro-optical/infrared (EO/IR) pods can now deliver military-grade multi-spectral imaging without compromising the aircraft's fuel or battery weight allocation. Furthermore, the minimal weighting of Procurement Cost (C3) explicitly indicates that when national sovereignty and long-term border security are threatened, fiscal austerity must be subordinated to operational efficacy. This prioritizations profile aligns with the structural defense procurement patterns observed by Smith and Jones (2023), who demonstrated that purchasing cheap, unhardened systems ultimately inflates long-term operational expenditures due to high combat attrition rates and frequent system replacements. Investing in premium, endurant, and cyber-resilient UAV platforms represents a more cost-effective strategy over the asset lifecycle.

From a policy perspective, the derived AHP model offers a formalized, mathematically repeatable blueprint for the Ministry of Defense and the TNI Headquarters during upcoming defense acquisition cycles under the post-Minimum Essential Force (MEF) guidelines. Instead of utilizing unweighted baseline checklists or evaluating platforms purely on unit purchase price, procurement committees should institutionalize these derived weights into their formal requests for proposals (RFPs). Contracts should be awarded using a composite scoring index where technical endurance parameters and electronic counter-countermeasure (ECCM) certifications are granted the highest multiplier effects. By implementing this quantitative framework, Indonesia can systematically insulate its defense procurement process from qualitative biases, political lobbies, and short-sighted budgetary cuts, ensuring that every rupiah invested directly enhances the nation's strategic deterrence capability across its vast archipelagic domain.

5. Conclusion

This study has successfully established a mathematically rigorous Multi-Criteria Decision-Making (MCDM) model to prioritize Unmanned Aerial Vehicle (UAV) selection criteria for Indonesia's archipelagic border defense. By formalizing the expert consensus from the Indonesia Defense University (Unhan) via Saaty's Analytical Hierarchy Process (AHP), the empirical results demonstrate that Flight Endurance (C1) and Cyber-Defense Capability (C4) dominate the strategic procurement paradigm, capturing 38.70% and 36.75% of the priority weight, respectively. The negligible variance between these two vectors reveals that modern military planners heavily prioritize platform survivability and electronic resilience over pure hardware capacity and fiscal constraints. Conversely, Payload Capacity (C2) at 17.17% and Procurement Cost (C3) at 7.39% occupy subordinate positions, establishing that traditional procurement checklists focused heavily on unit price or massive sensor integration are obsolete when confronted with volatile airspace frictions and high-intensity electronic warfare.

The theoretical contribution of this research lies in its systemic synthesis of electronic and cyber-warfare variables within archipelagic territorial defense frameworks, expanding traditional multi-criteria defense literature. Practially, the model delivers an objective, transparent, and mathematically validated blueprint for the Indonesian Ministry of Defense and the TNI Headquarters. Institutionalizing these derived weights within formal requests for proposals (RFPs) and operational evaluations will isolate defense acquisitions from qualitative biases, administrative lobbying, and counterproductive budgetary austerity. This quantitative alignment ensures that state expenditures are optimized to procure long-range, cyber-hardened unmanned systems that directly enhance domain awareness and sovereign deterrence across Indonesia's critical maritime border frontiers.

Despite its structural and mathematical validity, certain limitations must be acknowledged. This research focuses exclusively on high-level strategic evaluation criteria weights rather than conducting a direct performance ranking of specific commercial or military UAV brands. Furthermore, the AHP model operates under a deterministic environment using Saaty's standard linear scale, which may not completely capture the extreme cognitive fuzziness inherent in rapid technological advancements. Consequently, future research should extend this framework by incorporating Fuzzy-AHP or spherical fuzzy sets to accommodate ambiguous expert judgments. Additionally, downstream integration with hybrid MCDM methodologies, such as TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) or VIKOR, should be deployed to evaluate and rank specific operational MALE (Medium-Altitude Long-Endurance) drone platforms against the baseline weights established in this study.

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